

**UNITED STATES PATENT APPLICATION**

**OF**

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**FOR**

**LIQUID CRYSTAL DISPLAY DEVICE AND ITS FABRICATING METHOD**

This application claims the benefit of Korean Patent Application No. 2000-8042, filed on February 19, 2000, which is hereby incorporated by reference.

### **BACKGROUND OF THE INVENTION**

#### **Field of the Invention**

5 The present invention relates to a liquid crystal display (LCD) device, and more particularly, to an active matrix LCD (AM-LCD) device having thin film transistors (TFTs).

#### **Discussion of the Related Art**

10 Because liquid crystal display (LCD) devices are light, thin, and consume low power they are widely used in office automation equipment and video devices. LCDs are based on the optical anisotropy of a liquid crystal (LC). A LC has long, thin molecules whose orientational alignment can be controlled by an applied electric field. When the alignment of the LC molecules is correct, an applied light is refracted along the alignment direction of the 15 LC molecules such that an image is displayed.

Active matrix (AM) LCDs, in which thin film transistors (TFTs) and pixel electrodes are arranged in an array matrix, are typically used because of their high resolution and superiority in displaying moving images. In an AM LCD each TFT serves as a switch for a corresponding pixel. A switched on pixel transmits incident light. Since amorphous silicon 20 is relatively easy to form on large, relatively inexpensive, glass substrates, amorphous silicon thin film transistors (a-Si:H TFT) are widely used.

Figure 1 is a cross-sectional view illustrating a conventional LCD panel 20. As shown, the LCD panel has lower and upper substrates 2 and 4, and an interposed liquid

5 crystal layer 10. The lower substrate 2 includes a substrate 1, a TFT "S" as a switching element to selectively change the orientation of the liquid crystal molecules, and a pixel electrode 14 for the application of a voltage that produces an electric field across the liquid crystal layer 10 in accordance with signals from the TFT "S". The upper substrate 4 has a color filter 8 for implementing color. A common electrode 12 is formed on the color filter 8. The common electrode 12 serves as the other electrode for producing the electric field across the liquid crystal layer 10. The pixel electrode 14 is arranged over a pixel portion "P", i.e., a display area. Further, to prevent leakage of the liquid crystal layer 10 between the substrates 2 and 4, the substrates 2 and 4 are sealed by a sealant 6. The nematic, smectic, and cholesteric liquid crystals are most widely used in the above-mentioned LCD panel.

10 Figure 2 is a plan view illustrating the lower substrate 2 of the typical LCD device shown in Figure 1. As shown, on a substrate (reference 1 of Figure), a gate line 22 is arranged in a transverse direction, and a data line 24 is arranged perpendicular to the gate line 22. The TFT "S" is arranged at a crossing point of the gate and data lines 22 and 24. The pixel electrode 14 is arranged on a pixel region (reference "P" of Figure 1) defined by the gate and data lines 22 and 24. The TFT "S" includes a gate electrode 26, a source electrode 28 and a drain electrode 30. The gate electrode 26 electrically connects with the gate line 22, and the source electrode 28 electrically connects with the data line 24. The drain electrode 30 electrically connects with the pixel electrode 14 through a drain contact hole 32.

15 20 Still referring to Figure 2, gate and data pads 21 and 23 are integrally formed as terminal portions of the gate and data lines 22 and 24, respectively. Over the gate and data pads 21 and 23 are a gate pad electrode 34 and a data pad electrode 36. The gate and data pads 21 and 23 are electrically connected with the gate pad electrode 34 and the data pad

electrode 36 via a gate pad contact hole 42 and a data pad contact hole 44, respectively. The gate pad electrode 34 and the data pad electrode 36 are electrically connected with external driving circuits (not shown) that drive the TFT "S" and the pixel electrode 14.

In addition, a storage capacitor "Cst" is formed over a portion of the gate line

5 22. The storage capacitor "Cst" stores electric charge. When an electric signal is applied to the gate electrode 26 of the TFT "S", a data signal can be applied to the pixel electrode 14. Thus, unless the electric signal is applied to the gate electrode 26, a data signal cannot be applied to the pixel electrode 14.

A process for manufacturing the array substrate 2 requires repeated steps of depositing and patterning of various layers. The patterning steps use photolithography masks to control light exposing. As each photolithography step requires a mask, the number of masks required controls the number of patterning steps. As the number of masks decreases, the fabricating process becomes simpler and fewer errors tend to occur.

The fabricating process for the array substrate is determined by the design specifications for the array substrate and the materials used for the various layers. For example, when fabricating a large (say above about 12 inches) LCD device, the resistance of the gate line material can be a critical factor in determining the quality of the LCD device. Therefore, a highly conductive metal, such as aluminum (AL) or an aluminum alloy, is usually used for the gate lines of large LCD devices.

20 The general manufacturing process for the lower substrate 2 will be explained with reference to Figures 3A to 3E. In practice, an inverted staggered type TFT is widely employed due to its advantages of simplicity and high quality. The inverted staggered type TFT can be classified as either a back-channel-etch type or an etching-stopper type, based on

the method of forming a channel. As the back-channel-etch type has a simpler structure, Figures 3A to 3E show a manufacturing process that produces back-channel-etch type TFTs.

Figures 3A to 3E are sequential cross sectional views taken along lines "A-A" and "B-B" of Figure 2. At first, extraneous substances and organic materials are removed 5 from a substrate 1. By cleaning the substrate 1 the adhesion between the substrate 1 and subsequently formed layers is increased. After cleaning, a first metallic material is deposited on the substrate 1 and patterned via photolithography using a first mask to produce a gate electrode 26, a gate line (not shown in Figure 3A, but reference element 22 of Figure 2), and a first capacitor electrode 22a. Aluminum (Al) is a widely used first metallic material because it 10 has a low resistance that reduces RC delays. However, pure aluminum often produces hillocks that can cause defects. Therefore, an aluminum alloy (or an aluminum layer that is covered by another metal) is usually used instead of pure aluminum.

Next, as shown in Figure 3B, a gate insulating layer 50 is deposited on the exposed surface of the substrate 1 such that the gate insulating layer 50 covers the gate line, including the gate electrode 26, and the first capacitor electrode 22a. Thereafter, a pure amorphous silicon layer (a-Si:H) 52 and a doped amorphous silicon layer ( $n^+$ a-Si:H) 54 are sequentially deposited on the gate insulating layer 50. The amorphous silicon layer and the doped amorphous silicon layer 52 and 54 are then patterned into an active layer 55 and a semiconductor island 53, using a second mask. The doped amorphous silicon layer 54 reduces 15 the contact resistance between the active layer 55 and a metal layer that will be subsequently formed over the active layer 55. The doped amorphous silicon layer 54 is often called an ohmic contact layer.

Subsequently, as shown in Figure 3C, a second metallic material is deposited and patterned using a third mask into source and drain electrodes 28 and 30, a data line 24 (also see Figure 2), and a second capacitor electrode 58. Beneficially, the second metallic material is either chromium (Cr) or a chromium alloy. The second capacitor 58 is formed on 5 the gate insulating layer 50 and overlaps a portion of the first capacitor electrode 22a. This forms the storage capacitor Cst (see Figure 2).

Thereafter, using the source and drain electrodes 28 and 30 as a mask, a portion of the ohmic contact layer 54 is etched away to form a channel 38 between the source and drain electrodes 28 and 30. However, there is no etching selectivity between the ohmic contact layer 54 and the amorphous silicon layer 52. Therefore, etching the ohmic contact layer should be performed very carefully. In practice, about 50 to 100 nm of the amorphous silicon layer 52 is etched away when forming the channel. The electrical properties of the TFT "S" directly depend on the etching uniformity of the over-etched portion of the amorphous silicon layer 52.

15 Next, as shown in Figure 3D, an insulating layer is deposited and patterned using a fourth mask to form a passivation layer 56, which serves to protect the active layer 55. The passivation layer 56 is either an inorganic material such as silicon oxide ( $SiO_2$ ), or an 20 organic material such as benzocyclobutene (BCB). Those materials have high light-transmittance, good humidity resistance, and good reliability, all of which are required. In addition, a data pad contact hole 40, a drain contact hole 32, and a storage contact hole 42 are formed through the passivation layer 56 to respectively expose portions of the second storage electrode 58, the drain electrode 30, and the data pad 23. The drain contact hole 32 and the storage contact hole 40 respectively serve to electrically connect the drain electrode 30 and

second storage electrode 58 to a pixel electrode 14 (see Figure 2 and Figure 3E). Further, the data pad contact hole 42 serves to electrically connect the data line 24 with a data pad electrode 36 (also see Figure 2 and Figure 3E).

Next, as shown in Figure 3E, a transparent conductive material is deposited on 5 the passivation layer 56. That transparent conductive material is then patterned using a fifth mask to form the pixel electrode 14, the data pad electrode 36, and a gate pad electrode (reference 34 of Figure 2). Indium tin oxide (ITO) is beneficially used for the pixel electrode 14. As previously mentioned, the pixel electrode 14 electrically contacts the drain electrode 30 and second storage electrode 58 via the drain contact hole 34 and storage contact hole 40, respectively.

The fabricating process for the above-described LCD device uses at least five 10 masks. However, if the gate electrode is made of aluminum at least two additional masks are required to address hillocks on the surface of the aluminum layer. Therefore, the conventional 15 manufacturing process for an array substrate requires five to seven masks. As each mask process requires various steps, such as cleaning, depositing, baking, and etching, a reduction of one mask significantly reduces production costs and improves manufacturing yield.

For the foregoing reasons, a four-mask process for fabricating LCD devices 20 has been developed. In the conventional four-mask process the active layer 55 of Figure 3B is not patterned by itself. Instead, the source and drain electrode 28 and 30 are formed on the doped amorphous silicon layer 54. Then the various layers are patterned together. With 25 reference to Figure 4, the conventional four-mask will now be explained.

Figure 4 is a cross-sectional view taken along a line "IV-IV" of Figure 2. As 30 shown, a gate pad 21 electrically contacts a gate pad electrode 34. First, a gate pad 21 is

formed on the substrate 1. Then, a gate insulating layer 50, an amorphous silicon layer 57, and a passivation layer 56 are sequentially formed over the substrate 1. When the drain contact hole (reference 32 of Figures 2 and 3D) is patterned through the passivation layer 56, a gate pad contact hole 44 is formed through the gate insulating layer 50, the amorphous silicon layer 57, and the passivation layer 56. Therefore, a portion of the gate pad 21 is exposed by the gate pad contact hole 44. When a gate pad electrode 34 is formed over the gate pad 21, they are electrically connected to each other via the data pad contact hole 44.

The gate pad electrode 34 is comprised of the same material, a transparent conductive material, as the pixel electrode 14 (see Figure 3E). Unfortunately, the transparent conductive material, usually indium tin oxide (ITO), has poor step coverage. Therefore, if the transparent conductive material is formed along a large step, such as at the gate pad contact hole 44, the transparent conductive material is easily broken. Because the amorphous silicon layer 57 was not patterned in a previous step, the step at the gate pad contact hole is particularly large. Thus, open line defects 60 tend to occur along the gate pad electrode 34.

Such open line defects 60 cause abnormal operation of the LCD device.

### SUMMARY OF THE INVENTION

Accordingly, the present invention is directed to a reflective LCD device that substantially obviates one or more of the problems due to limitations and disadvantages of the related art.

An object of the present invention is to provide an improved four mask fabrication process for liquid crystal display devices.

To achieve the above object, the principles of the present invention provide for a novel liquid crystal display device. That device includes a substrate with a thin film transistor having a gate electrode, a source electrode, and a drain electrode. A pixel electrode electrically connects with the drain electrode, and a data line electrically connects with the source electrode. A first insulating layer, a pure amorphous silicon layer, and a doped amorphous silicon layer are sequentially layered under the data line. A data pad is at one end of the data line. A gate line electrically connects to the gate electrode of the thin film transistor and to a gate pad electrode at one end of the gate line. The gate pad electrode is formed on the first insulating layer and in a hole through the first insulating layer that exposes a portion of the gate line. Thus, the gate pad electrode electrically contacts the exposed portion of the gate line.

The pixel electrode is beneficially selected from a group consisting of indium tin oxide (ITO) and indium zinc oxide (IZO).

The drain electrode is electrically connected to the pixel electrode via a drain hole through the first insulating layer such that the pixel electrode electrically contacts an inner side surface of the drain electrode.

A data pad contact hole passes through the doped amorphous silicon layer and through the amorphous silicon layer. The same material that comprises the pixel electrode electrically contacts an inner side surface of the data pad via the data pad contact hole.

In another aspect, the present invention provides a method of fabricating a liquid crystal display device. The method includes preparing a substrate and then forming a gate electrode on the substrate by depositing and patterning a first metal layer. Next, a gate insulating layer is formed on the gate electrode, followed by the formation of a silicon layer

on the gate insulating layer. Next, a data line, a source electrode, a drain electrode, and a data pad are formed by depositing and patterning a second metal layer on the silicon layer. Next, forming a passivation layer on the data line, the source electrode, and drain electrode such that the passivation layer exposes portions of the data pad and the drain electrode. The 5 method continues by forming a data pad contact hole and a drain contact hole, respectively, on the exposed portions of the data pad and drain electrode such that portions of the gate insulating layer are exposed. Next, forming a pixel electrode and a data pad electrode by depositing and patterning a transparent conductive material on the passivation layer such that the pixel electrode and the data pad electrode electrically contact the drain electrode and data pad, respectively.

The data pad electrode beneficially contacts an inner side surface of the data pad via the data pad contact hole. The pixel electrode beneficially contacts an inner side surface of the drain electrode via the drain contact hole.

It is to be understood that both the foregoing general description and the 15 following detailed description are exemplary and explanatory and are intended to provide a further explanation of the invention as claimed.

#### BRIEF DESCRIPTION OF THE DRAWING

The accompanying drawings, which are included to provide a further 20 understanding of the invention and are incorporated in and constitute a part of this specification, illustrate an embodiment of the invention and together with the description serve to explain the principles of the invention.

In the drawings:

FIG. 1 is a cross-sectional view illustrating a liquid crystal display device according to the related art;

FIG. 2 is a plan view of the LCD device according to the related art;

5 FIGS. 3A to 3E are sequential cross-sectional views illustrating a five mask fabricating process for LCD devices according to the related art;

10 FIG. 4 is a cross-sectional view taken along a line "IV-IV" of FIG. 2, wherein a conventional fabricating process using four masks is applied to LCD device;

15 FIG. 5 is a plan view of an LCD device according to a preferred embodiment of the present invention;

20 FIGS. 6A to 6D are sequential cross-sectional views taken along a line "VI-VI" of FIG. 5; and

25 FIGS. 7A to 7C are cross-sectional views taken along a line "VII-VII" of FIG. 5.

#### DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

Reference will now be made in detail to the illustrated embodiment of the present invention, an example of which is shown in the accompanying drawings.

As shown in Figure 5, a gate line 100 is transversely formed on a substrate 20 (reference 90 of Figure 6A), and a data line 110 is arranged perpendicular to the gate line 100. On a pixel region (reference "P" of Figure 1) defined by the gate and data lines 100 and 110, is a pixel electrode 118. At the crossing of the gate and data lines 100 and 110 is a gate electrode 102 that extends from the gate line 100. At one end of the gate line 100 is a gate pad

104. A gate pad electrode 108 is formed over the gate pad 104. The gate pad 104 electrically connects to the gate pad electrode 108 via a gate pad contact hole 106 formed through the gate pad 104.

A source electrode 114 extends from the data line 110 such that the source 5 electrode overlaps the gate electrode 102. A data pad 120 is formed at one end of the data line 110. A data pad electrode 124 is formed over the data pad 120. The data pad electrode 124 and the data pad 120 are electrically connected together via a data pad contact hole 122. The data pad contact hole 122 preferably includes a plurality of holes formed through the data pad 120 such that the contact resistance between the data pad 120 and the data pad electrode 124 is reduced. Furthermore, the data pad electrode 124 contacts an inner side surface of the data pad 120, or an inner side surface of the data pad contact hole 122 is formed through the data pad 120. This side surface contact will be explained in more detail subsequently.

Still referring to Figure 5, a drain electrode 116 is formed opposite the source electrode 114. A drain contact hole 117 is formed through the drain electrode 116. The drain electrode 116 electrically contacts the pixel electrode 118 via the drain contact hole 117. Like the contact between the data pad and the data pad electrode 120 and 124, the pixel electrode 118 electrically contacts an inner side surface of the drain electrode 116, or an inner side surface of the drain contact hole 117. A more detailed explanation about the side surface contacts is provided below.

20 With reference to Figures 6A to 6D, a fabricating process for the inventive LCD device will now be provided. As shown in Figure 6A, a first metal layer is deposited and patterned on the substrate 90 using a first mask to form the gate line (reference element 100 of Figure 5), the gate electrode 102, and the gate pad (reference element 104 of Figure 5). A

gate insulating layer 150 is subsequently formed over the gate line, gate electrode, gate pad, and substrate 90. Thereafter, a pure amorphous silicon layer 152, a doped amorphous silicon layer 154, and a second metal layer 156 are sequentially formed on the gate insulating layer 150. The second metal layer 156 is preferably molybdenum (Mo) or the like that can be 5 etched using a dry etch method.

Next, as shown in Figure 6B, the second metal layer 156 is etched using a second mask to form the source and drain electrodes 114 and 116, data line 110, and data pad 120. Using the source and drain electrodes 114 and 116 as a mask, the doped amorphous silicon layer 154 is subsequently etched to form a channel "CH" between the source and drain electrodes 114 and 116. Thereafter, a passivation layer 112 is deposited and patterned using a third mask to cover the source electrode 114, drain electrode 116, and data line 110. The passivation layer 112 is also patterned to have first and second through holes 117a and 122a, which respectively expose portions of the drain electrode 116 and data pad 120.

Next, as shown in Figure 6C, using the passivation layer 112 as a mask, the 15 exposed doped amorphous silicon layer 154 is etched away. The exposed portions of the drain electrode 116 and data pad 120 are also etched away such that the drain contact hole 122 and the data pad contact hole 117 are formed. Since the drain electrode 116 and the data pad 120 are comprised of a metal that can be dry-etched it is possible to etch both the metal and the 20 doped amorphous silicon layer 152 together. The drain contact hole 122 and the data pad contact hole 117 expose inner side portions of the drain electrode 116 and the data pad 120, and planar portions of the gate insulating layer 150.

Next, as shown in Figure 6D, a transparent conductive material is deposited on the passivation layer 112 and then patterned using a fourth mask such that the pixel electrode

118, the data pad electrode 124, and the gate pad electrode (reference 108 of Figure 5) are formed. The transparent conductive material is preferably selected from a group consisting of indium tin oxide (ITO) and indium zinc oxide (IZO). The pixel electrode 118 and the data pad electrode 122 are formed so as to contact the inner surfaces of the drain contact hole 117 and 5 data pad contact hole 122, respectively. Therefore, the pixel electrode 118 and the data pad electrode 124 electrically contact the inner side surfaces "Z1" and "Z2" of the drain electrode 116 and the data pad 120, respectively.

Now, with reference to Figures 7A to 7C, the structure of the gate pad contact hole according to the preferred embodiment is explained.

Figure 7A to 7C are cross-sectional views taken along line "VII-VII" of Figure 5 during the fabrication process. As shown in Figure 7A, just after the patterning of the passivation layer 112 explained with the assistance of Figure 6B, a photoresist pattern 172 is on the passivation layer 112 covering the data line 110. The photoresist pattern 172 was formed using the third mask, which was used to pattern the passivation layer 112. The 15 passivation layer 112 was patterned using the photoresist pattern 172 such that the passivation layer was etched away, except for the passivation layer under the photoresist pattern 172. The first and second through holes (reference 117a and 122a, see Figure 6C) have been formed through the passivation layer 112.

An auxiliary metal pattern 170 is present over the gate pad 104, and a third 20 through hole 106a that corresponds to the position of the gate pad 104 is formed through the auxiliary metal pattern 170. The auxiliary metal pattern 170 is formed from the same material as, and along with, the data line 110. The auxiliary metal pattern 170 serves as an etching stopper, which will be explained later.

Next, as shown in Figure 7B, the pure amorphous silicon layer 152 is etched away, except for under the auxiliary metal pattern 170, under the passivation layer 112, and under the photoresist 172. That is to say, the auxiliary metal pattern 170, passivation layer 112, and photoresist 172 act as a mask. Thereafter, as shown in Figure 7C, the auxiliary metal 5 layer 170 and portions of the gate insulating layer 150 are etched away such that the gate pad contact hole 106 is fully formed, thus exposing the gate pad 104, and such that the doped amorphous silicon layer 154 is exposed.

Next, as shown in Figure 7D, the silicon layers 154 and 152 are etched away to expose the gate insulating layer 150 around the gate pad 104. Then, as shown in Figure 7E, the gate pad electrode 108 is formed over the gate pad 104 such that the gate pad electrode 108 electrically contacts the gate pad 104 via the gate pad contact hole 106. Compared with a conventional gate pad contact hole shown in Figure 4, the inventive gate pad contact hole 106 has a significantly small step. Therefore, the step coverage of the transparent conductive material, preferably indium tin oxide (ITO) or indium zinc oxide (IZO), is better than with the conventional gate pad contact hole shown in Figure 4. Accordingly, the number of open line 10 15 defects as illustrated in Figure 4 are reduced.

It will be apparent to those skilled in the art that various modifications and variation can be made in the illustrated device and method without departing from the spirit or scope of the invention. Thus, it is intended that the present invention covers the 20 modifications and variations of this invention that come within the scope of the appended claims and their equivalents.